POTABILITY OF BOREHOLE, BOTTLED, AND MUNICIPAL WATER IN HARARE

By

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ABSTRACT

Human health depends on reliable access to safe drinking water, but in many developing countries there are problems of accessing it. This is mainly attributed to water pollution, poor infrastructure for potable water treatment and unhygienic practices in water bottling companies. This study was carried out to assess the physico-chemical and microbiological quality of borehole, bottled and municipal water in Harare (Zimbabwe), by evaluating the compliance of each water type with WHO standards. The study period was from February 2012 to May 2012. Water samples were collected from five boreholes in different high density suburbs, five different brands of bottled water and municipal water. A total of 180 samples were collected and each was analysed for 17 parameters. Standard Operation Procedures (SOPs) at EMA laboratory were followed for analysis of these parameters. All the bottled water brands and municipal water tested negative for all faecal coliforms. All chemical parameters in bottled and municipal water complied with WHO standards. Heterotrophic bacteria were within WHO standards (100 colonies/ 100 ml) in municipal water and in all bottled water brands except for brands B and C. The occurrence of heterotrophic bacteria in some bottled water brands exposes consumers to gastrointestinal diseases. All microbiological parameters complied with WHO standards in boreholes A and B. However pH, manganese and nitrates did not comply with WHO standards in boreholes A and B. Faecal coliforms were detected in boreholes D and E. The concentration of heavy metals in boreholes C, D and E did not comply with WHO standards. High concentration of heavy metals predisposes consumers to health problems such as bioaccumulation of heavy metals. Borehole E had the highest TDS (1180.83 mg l^{-1}) which did not comply with WHO standards. Overall, each borehole in Harare failed to comply with WHO standards for most parameters. The results suggest that the safest water to drink in Harare is municipal water because it showed consistent compliance with WHO standards in all tested parameters. For bottled water not all brands are safe (3 out of 5 complied). Brand E (carbonated water) proved to be the safest among other brands as no bacteria were detected.

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DEDICATION

I dedicate this work to the most special loving people in my life i.e. my father and mother. I really appreciate their hard work, love, care and support which made me a beautiful thing l am up to this day.

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CHAPTER 1: INTRODUCTION

1.1 Background

Harare, the capital city of Zimbabwe, has grown bigger owing to population growth and rural-urban migration. The Harare population has increased by 1.1% from the last census carried out in 2002. The population of Harare in 2012 was above two million, which is more than 16% of the total population (above12 million) of Zimbabwe (ZimStat, 2012). The population has now exceeded the carrying capacity of water supply resources and waste management infrastructure (ZINWA, 2012). This has put a lot of pressure on the water resources in Harare. Harare municipal water supplies are producing a mere 650 mega-litres of water against a demand of 1 400 mega litres per day. This has resulted in shortage of potable water in the city. To mitigate this challenge, the City Council came up with a water rationing strategy to ensure that every area in Harare receives tap water per given hours daily (Hove and Tirimboi , 2011). Besides failure to meet demand, there are concerns about the quality of water from municipal supplies. These concerns were raised by the typhoid and cholera outbreaks (Musemwa, 2008).

As a result of this short supply of potable water, Harare residents have resorted to alternative sources of water including bottled water from water bottling companies and community boreholes. Most Harare residents now prefer to drink borehole and bottled water to municipal water for since they perceive the former to be of higher quality than the latter (Musemwa, 2008). Residents believe that the quality of municipal water is compromised because there had been cholera and typhoid outbreaks (ZINWA, 2012). They also avoid consuming municipal water because they think it contains hazardous chemicals (ZINWA, 2011). Bottled water and borehole water is thought to be free from contamination since it undergoes standardized purification processes and is protected from the toxic environment, respectively. Even though it is mandatory for all bottled water companies to register for quality production there are influxes of counterfeit and/ or unregistered brands in the market which could pose threat on human health (EMA, 2008).

There have been a lot of human activities in Harare such as improper disposal of household and industrial waste such as detergents, batteries and paint, heavy use of fertilizers and pesticides, which can cause groundwater contamination and affect the quality of borehole water. Poor maintenance of sewer system and use of bush toilets can also attribute to groundwater pollution in Harare.

Of late there have been outbreaks of waterborne diseases in Harare especially in high density areas (Musemwa, 2008). The outbreaks have claimed more than a thousand lives in Zimbabwe. The epidemic is not only related to water quantity but also water quality. This is because water of poor quality contains many pathogens which cause communicable diseases such as cholera and typhoid (Jonga and Chirisa , 2009)

1.2 Problem statement

Given the three sources of drinking water, i.e. bottled water, borehole water and municipal water, there have been some arguments on which water is the safest to drink in Harare. The arguments are attributed to the cholera and typhoid outbreaks which occurred lately. Harare residents are not certain of which water is safest to drink in relation to their health. This has resulted in some people spending a lot of money on bottled water or spending time in fetching borehole water just in the name of avoiding the affordable municipal water. Only a few people rely on municipal water for drinking.

1.3 Justification

It is important to ascertain the safety of drinking water because safe drinking water is fundamental to the protection of public health (Pedley and Howard, 1997). Lack of safe drinking water supply is associated with high morbidity and mortality, especially in urban areas (Pedley and Howard, 1997).

Evaluation of domestic water quality is of importance as it helps to achieve the United Nations Millennium Development Goal 7 of decreasing the proportion of people without sustainable access to safe drinking water. Access to clean safe potable water is a declared human right (U.N, 2006).

Ogan (1999) recommended regular monitoring of bottled water, borehole water and municipal water. In his study he emphasized that even if bottled water is believed to be safe it may contain microbes as high as 10 cfu ml^{-1}. In a study carried out by Grant (2007), 36 bottled water brands out of 104 brands from ten countries tested positive for presumptive coliforms. A variety of pathogenic organisms have been recovered from bottled water. Some of the organisms include *Salmonella, Nor virus, Staphylococci* and *Vibrio cholerae* (Svagzidiene and Page 2010).

This indicates that bottled water is not necessarily safe; therefore it is necessary to assess bottled water quality. There are allegations that most bottling companies in Harare bottle their water straight from the raw water source without treating the water or making quality assurance operations, therefore it is necessary to assess its safety.

Hassel and Capil (2000) recommended municipal water to be safer than other drinking water sources given that municipal water has residual disinfection effect of chlorine. However, in

Canada municipal water was regarded as safer until in April 2000 when *E.coli* and *Cryptosporidium* were found in the water after causing a massive death of people (Svagzidiene and Page, 2010).

Apart from the effect of underlying geology, borehole water quality could be compromised by groundwater contamination (Pedley and Howard, 1997). The chances of groundwater contamination in Harare are high. Sewage bursts are most common in high density suburbs and this can contaminate groundwater through infiltration. Contaminants leaching from inactive mine sites, dumping sites, fertilized lands and improper siting of septic tanks contribute to groundwater contamination. Biofilm formation sometimes encourages the growth of bacteria in ground water. From 1997 to 1998, 17 waterborne disease outbreaks were recorded in the USA, 15 (88%) of which were related to groundwater sources ((Pedley and Howard, 1997). Therefore groundwater quality should be known so as to ascertain if it needs treatment before consumption

1.4 Objectives

1.4.1 Main objective

To assess the physico-chemical and microbial quality of bottled water, borehole water and municipal water in Harare and evaluate its compliance with WHO recommended standards.

1.4.2 Specific objectives

- To analyze water samples for biological oxygen demand (BOD), total dissolved solids (TDS), electrical conductivity (EC), total hardness (TH), iron, magnesium, zinc, sodium, lead, pH, manganese, nitrates, *Escherichia coli (E.coli),* total coliform, faecal *streptococci*, heterotrophic plate count (HTC) at 22 ^{o}C and at 37 ^{o}C.

- To evaluate the compliance of each water source (i.e. municipal, borehole and different brands of bottled water) with WHO standards (the recommended limit).
- To infer on the health implications of using the three sources of water.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Water is essential to sustain life, and without it life becomes impossible (WHO, 2012). This makes it an indispensable commodity, which should be easily accessible, adequate, free of contamination, safe, affordable and available throughout the year in order to sustain life (Al-Khatib *et al.*, 2003). In developing countries, thousands of children under five years die every day due to drinking contaminated water (WHO, 2004). Thus lack of safe drinking water supply, basic sanitation and hygienic practices is associated with high morbidity and mortality from excreta related diseases. About 22 African countries, including Malawi, fail to provide safe drinking water to half of their population (Vinod *et al.*, 2008).

The lack of safe drinking water and adequate sanitation measures leads to a number of diseases such as dysentery, salmonelosis, shigellosis and typhoid, and every year millions of lives are claimed in developing countries. In some individuals some waterborne pathogens do not cause clinical symptoms, posing a risk to others as these pathogens then have a "silent" reservoir from which they are released. Primary waterborne transmission often goes unnoticed because only after secondary or tertiary transmission does a disease manifests itself clinically (Stenhammar, 1999).

The pressures put on water resources include direct contamination from domestic, industrial, and agricultural wastes and less direct effects caused by climate change and other ecological disturbances. The result from these pressures is water pollution which in turn contributes to waterborne disease outbreaks worldwide. Water pollution also increases the chemicals of water treatment, thereby making it expensive. Lake Chivero is now hyper- eutrophicated such that the chemicals used to treat Harare municipal water have increased from three up to ten chemicals (ZINWA, 2012).

2.2 Drinking water quality

To safeguard human health, the World Health Organization (WHO) set international water quality (WQ) standards as a guideline of drinking water monitoring. These WQ standards are sets of qualitative and quantitative criteria designed to maintain and enhance the quality of water. The standards prescribe which substances can be in drinking water and maximum concentration of these substances (WHO, 2006).

Water Quality is determined by the concentration of biological, chemical and physical contaminants. A contaminant becomes a pollutant when it exceeds an acceptable concentration advised by WHO guidelines. Other than infectious diseases, some of the effects of pollutants on human health are; blue baby syndrome caused by higher levels of nitrates and poisoning caused by heavy metals (WHO, 2007).

Water quality standards have been developed to minimize known chemical and microbial risks. The term "safe" drinking water does not mean risk free; it simply means risks are very small, at or below our ability to quantify them, or that water quality limits cannot be lowered further by water treatment processes (Tobin *et al.*, 2003).

2.3 Borehole water

Rainwater moves downwards through cracks in the soil and fractures in rocks until it is intercepted by an impermeable layer of clay or rock. The water then accumulates on this layer filling up all available spaces until saturation. The top of the impermeable layer become the water table whilst the accumulated water becomes the ground water. This is how groundwater gets into the aquifier system (Nwale *et al.,* 2007).

Borehole water is derived from groundwater through mechanically or electrically driven pumps. The borehole pumps in this study are mechanically hand driven. Groundwater is actually a complex, generally dilute, chemical solution. The chemical composition is derived mainly from the dissolution of minerals in the soil and rocks with which it is or has been in contact. The type and extent of chemical contamination of the groundwater is largely dependent on the geochemistry of the soil through which the water flows prior to reaching the aquifers. (Abdulaziz, 2003). The chemical alteration of the groundwater depends on several factors, such as interaction with solid phases, residence time of groundwater, seepage of polluted runoff water, mixing of groundwater with pockets of saline water and anthropogenic impacts (Hussain *et al.*, 2002).

Groundwater in its natural state is generally of good quality. This is because rocks and their derivatives such as soils act as filters. However, not all soils are equally effective in this respect and therefore pathogens contained in human excreta such as bacteria and viruses are likely to be small enough to be transmitted through the soil and aquifer matrix to groundwater bodies (Myers, 2004). On the other hand, ground water may contain some natural impurities or contaminants, even without human activity or disturbance. Natural contaminants can come from many conditions in the watershed or in the ground. Water moving through underground rocks and soils may pick up magnesium, calcium and chlorides. Some ground water naturally contains dissolved elements such as arsenic, boron, selenium or radon a gas formed by the natural breakdown of radioactive uranium in soil. These natural contaminants become a health hazard when they are present in high doses (O'neil, 1993).

In addition to natural contaminants, ground water is often polluted by human activities such as improper use of fertilizers, animal manure, herbicides, insecticides and pesticides. Poorly built septic tanks and sewage systems for household wastewater, leaking or abandoned underground storage tanks, piping storm-waters drains that discharge chemicals to ground water and improper disposal or storage of waste chemical spills at local industrial sites all contribute to the pollution of ground water (Sharpley, 1999).

2.4 Municipal water

Potable water treatment is the process of enhancing drinking water quality so that it meets the standards of its use. Potable water treatment procedures are determined by the raw water quality. For example the Kariba water supply station only treats water through two processes; filtration and chlorination whereas Morton Jeffrey water works (Harare) employs a number of processes. The more polluted the water, the more chemicals and treatment procedures are required for treatment. Therefore raw water quality determines the quantities and type of chemicals to use. Hence the application of water treatment processes varies from area to area depending on the raw water quality (ZINWA, 2011).

2.4.1 Municipal water purification procedure

The water treatment process involves a series of different steps. The following are the basic processes involved in water treatment (ZINWA, 2011).

Preconditioning: pH correction is done before water treatment. This is because the water treatment chemicals work best at a neutral pH. Soda ash (for acidic water) and sulphuric acid (for alkaline water) is applied to neutralize the water. Algae are a phytoplankton which persists in purification plants. Algae are eliminated from raw water by pre-chlorination. In filter beds, sun blockers are used to eliminate sunlight penetration. Without the availability of sunlight, photosynthesis cannot occur thus algal growth will be inhibited. Algae give water a greenish colour and it adds an odorous smell to water. The odor is removed by adding activated carbon. The efficiency of activated carbon for biological treatment of drinking water is greater than the efficiency of conventional filtration media such as sand. Biological elimination of dissolved organic compounds offers water quality benefits.

Coagulation: this is the first stage where water is treated with a coagulant. Raw water is pumped from the source to the flocculation chamber. pH is tested because acidic pH affects the efficiency of coagulants. The suspended particles coagulate thereby forming flocs in a process known as flocculation. Coagulation removes colour and turbid from the water .The coagulant used in all ZINWA purification plants is aluminum sulphate. However some biological polymers under test are to be used because their advantages outweigh Aluminum sulphate. One of the advantages is that it is less toxic and it is economic because small doses treat large volumes of water. Jar tests are important in determining the average doses that can be used.

Sedimentation and clarification: After flocculation the heavy flocs settle down the sedimentation tank. The resultant supernatant flows from the sedimentation tanks to the filter beds via channels called launders. The flocs form sludge at the bottom of the tank. The sludge is removed by scouring the tank using scour valves.

Filtration: The supernatant is filtered through a 3 layered channel. The layers comprise of different sizes of soil particles which trap light suspended solids of different sizes. Filtration does not fully disinfect but it removes protozoa which is resistant to chlorination because it encysts. *Protozoa* invade the circulatory system through the digestive wall tissue. Protozoa also cause diarrheal diseases, for example *Entamoeba hystolica* invades intestinal mucosa causing amoeboid dysentery.

Chlorination: Disinfection is the last stage of the treatment processes. The filtrate is pumped to the sump for disinfection. Chlorine is the disinfectant used. Other options include ozonation and ultra violet radiation. Uniform distribution of f chlorine should be achieved to ensure maximum disinfection. The contact time of chlorine and bacteria should also be long enough to effect disinfection. Chlorine digests the bacterial membrane resulting in the complete destruction of the bacteria.

Tests: Before pumping the treated water to the reservoir quality tests are done. Total and residual chlorine is tested using DPD tablets and comparator discs which use the scope of colorimetry. Total Cl_2 should 1mg/l such that when it reaches the consumers it will be enough to effect disinfection. Residual chlorine should be 0.5mg/l. It is the amount of chlorine that reaches to consumer tap, it is determines effective disinfection. Turbidity and pH are tested as well. Microbiological tests are carried out to test the drinkability of water in relation to bacteriology.

2.4.2 Uses of chlorine

In addition to controlling disease-causing organisms, chlorination offers a number of benefits (Tobin *et al.*, 2003). It reduces many disagreeable tastes and odors; eliminates slime bacteria, molds and algae that commonly grow in water supply reservoirs, on the walls of water mains and in storage tanks; removes chemical compounds that have unpleasant tastes and hinder disinfection and helps remove iron and manganese from raw water.

Precise dosages of chlorine must be used because low dosages of chlorine cause injury to microbes. Injured bacteria may fail to grow under laboratory conditions, thus failure to detect the bacteria. Therefore results from microbiology analysis may conclude that water is free from contamination when bacteria are actually present. The risk from this is that the impure water containing injured pathogens will be assumed to comply with WHO guideline. This causes serious health vulnerability because injured pathogens have the potential to cause diseases (Maier *et al.*, 2000).

Drinking water quality can deteriorate substantially within distribution systems. This deterioration is exhibited by decreases in disinfectant residuals and increases in bacterial counts, sometimes to levels that affect public health. The processes that influence water quality decay are complex and depend on many factors, and the raw water properties that influence these factors differ greatly with location (Maier *et al.*, 2000).

In rare cases where there are broken pipes, cross contamination occurs between sewer pipes and potable water pipes. In Harare (Zimbabwe) boil water advisories are announced to the public in the cases when water quality is thought to have been compromised by cross contamination or by low dosages of chlorine (ZINWA, 2012).

2.4.3 Disinfectant by products

ZINWA emphasized the importance of controlling disinfection byproducts (DBPs) or trihalomethanes (THMs) and chemical compounds formed unintentionally when chlorine and other disinfectants react with natural organic matter in water. These products were discovered by United States Environment Protecting Agency (USEPA) in the 1970s. High levels of these chemicals are undesirable. Affordable methods to remove these products are available and should be used (EPA, 2011). In Zimbabwe, the removal of these by products has not yet been adopted (ZINWA, 2012).

On the issue of DBPS, the International Programme on Chemical Safety (IPCS) (2000) reached a conclusion that disinfection is the most important step in the treatment of water in drinking water supplies. Therefore the microbial quality of drinking water should not be compromised because of the concern over the long term effects of disinfectants and their by-product. The risk of illness and death resulting from exposure to pathogens in drinking water is very much greater than the risks from disinfectants and DBPs (IPCS, 2000).

The filtration of drinking water and the use of chlorine is probably the most significant public health advancement of the water treatment (Anon, 2002). Bacteria are the least troublesome and are generally removed by current water treatment processes. Therefore the effectiveness of water treatment varies depending upon whether the waterborne contaminant is bacteria, a virus or a protozoa parasite. Diseases such as Salmonella, Typhus, Dysentery and other bacterial diseases are fairly well controlled, at least in developed countries, through effective water treatment procedures (Hassan, 2011).

2.5 Bottled water

In Harare there are various water bottling companies. The quality of this bottled water brands is questionable because in another study by Warberton *et al.* (1999), it was found that three out thirty samples randomly selected from retail markets in Harare contained coliforms. The demand of bottled water has increased such the companies are more concerned about profit making than quality making. The water quality can be compromised by manufacturing procedures such as maintenance of aseptic techniques and hygienic practices during purification, packaging and storage. The length of shelf life was also found to affect the chemical and microbial quality, because some bacteria can grow after packaging and some chemicals can leach from the plastic bottles (WHO, 2006).

2.5.1 The basic purification procedure of bottled water (WHO, 2012)

Raw water is collected and received through stainless steel pipes from a well, borehole or municipal water. Quality testing of the original source is conducted regularly to monitor abnormalities. When water originates from a municipal water system, chlorine and THMs are removed through activated carbon filtration. A water softener is used to reduce water hardness. Removal of unwanted minerals (demineralization) is done through reverse osmosis (RO). Selected minerals are then added to enhance taste (WHO, 2012).

Pharmaceutical grade micro-filtration and is then done to remove particles as small as 0.2 microns. It is also capable of removing potential microbiological contaminants. Ultra –violet, ozonation and carbonation are disinfection processes prior to packaging. The filling room should be highly sanitary to ensure bottling is conducted in a microbiologically safe environment (WHO, 2012).

Quality inspection is normally done by qualified personnel’s. Usually each plant is equipped with a laboratory and quality assurance staff to analyze compliance with specifications and ensure that all aspects of the final product comply with company’s standards and other regulatory specifications. Some of the Quality assurance techniques involve, sterilizing bottles by ozonation, U.V light, caustic washing and or autoclaving and regular rehabilitation of filtration or osmosis membranes (WHO, 2012).

2.6. Microbial contamination

Infectious diseases caused by pathogenic bacteria, viruses and protozoa are most common and associated with drinking water (WHO, 1997). Esray *et al.* (1998) surveyed 142 studies on six major waterborne diseases and estimated that in developing countries, there were 875 million cases of diarrhea and 4.6 million deaths annually in the 1980s. The World Bank estimate that more than 3 million children die annually from diarrhea contracted through drinking water in the developing world (WHO, 2006).

One of the primary concerns of water authorities is to ensure that the drinking water they supply does not pose health risks to consumers: The safety of drinking water is generally monitored in a number of ways. One of the ways is to monitor indicator organisms of water quality. These indicator organisms are known as coliforms (Schmidt and Lorenz, 1999).

2.6.1 Coliforms

The concept of coliforms as bacterial indicators of microbial water quality is based on the idea that because coliforms are present in high numbers in human and other warm-blooded animals faeces. With exceptions, coliforms themselves are not considered to be a health risk, but their presence indicates that faecal contamination may have occurred and pathogens might be present as a result. It is acknowledged that the major threat to public health from drinking water is from microbiological contamination with human (WHO, 2006).

There are a number of problems associated with the direct assay of pathogens in water samples. Methods for pathogen recovery and detection are time-consuming, complex and costly due to the large number of different pathogens that can be present in water. Therefore indicator organisms are used. A direct assay for pathogens can be used if a particular water supply needs to be confirmed as a source of an enteric disease outbreak (Birke *et al.*, 2002).

However, the coliforms are not infallible. A study on the microbial contamination of groundwater sources in New South Wales in Australia reported the presence of both hepatitis A virus and Norwalk virus in boreholes where no bacterial faecal indicators were found (Savichtcheva and Okabe, 2006).

The coliforms mainly used in water quality are total coliform, *Escherichia coli* and faecal *streptococci. E.coli* strains are part of the normal microbial flora of gastro-intestinal tract of man and animals. There are certain *E.coli* strains which are pathogenic and cause characteristic diarrheal symptoms. An example of such a strain is *E.coli* 0157:H7. It causes hemorrhagic colitis characterized with blood stained diarrhea accompanied with abdominal pains. In infants it causes hemolytic uraemic syndrome characterized with acute renal failure and hemolytic anaemia (Elberg *et al.*, 2000).

Faecal streptococci are represented by various *Enterococci* species. Faecal streptococci rarely multiply in polluted water. They are highly resistant to drying and may be useful for detecting pollution of groundwater. *Enterococci* have a number of advantages as indicators over total coliforms and E.coli including that they do not grow in the environment, and they have been shown to survive longer. More recent research on the relevance of fecal streptococci as indicators of contamination showed that the majority of Enterococci (84%) isolated from a variety of contamination water sources were true fecal species (Elberg *et al.*, 2000).

2.6.2 Heterotrophic bacteria

Heterotrophic plate counts (HTC) assess the general microbial load of water. It does not represent all the bacteria present, but represents the bacteria that were able to grow and produce visible colonies on media used at prescribed temperature. The HTC bacteria at 22^{o}C and 37 ^{o}C are not related to faecal contamination. It is of little sanitary significance but is useful in the assessment of the efficiency of water purification (Maier *et al.*, 2000).

2.7 Physiochemical contamination

2.7.1 Metals

Metals are natural elements of the earth's crust. They cannot be degraded or destroyed. To a lesser extent they enter human body via eating, drinking and breathing. They are essential to maintain the metabolism of the human body but only at a prescribed concentration recommended by health specialists (Prater, 1999).

At higher concentrations, metals bioaccumulate in the body. Bioaccumulation is an increase in the concentration of a chemical in an organism over a long period. Compounds are stored faster than they are broken down (metabolized or excreted). Heavy metals can enter the water supply system through industrial and consumer waste, or even from acid rain breaking down soils and releasing heavy metals into streams, lakes, rivers, and groundwater (0'Neil, 1993).

Iron

Making up at least 5 % of the earth's crust, iron is one of the earth's most plentiful resources. It is one of the most troublesome elements in water supplies. Rainwater as it infiltrates the soil and underlying geological formations dissolves iron causing it to seep into the aquifer that serves as source of ground water for bore holes. Although present in drinking water, iron is seldom found at concentrations greater than 10mg/l. Iron is not hazardous to health but it is considered a secondary or esthetic contaminant. Essential for good health, iron helps transport of oxygen in the blood. Concentrations of iron as low as 0.3mg/l will leave reddish brown stains on fixtures, tableware and laundry that is very hard to remove. When these deposits break loose, from water piping, rusty water will flow through the faucet (Myers, 2004).

Lead

Lead found in fresh water usually indicates contamination from metallurgical waste or from lead-containing industrial poisons. Lead in drinking water is primarily from the corrosion of the lead used to put together the copper piping. Lead can be reduced considerably with a water softener activated carbon; filtration can also reduce lead to a certain extent. Reverse osmosis can remove 94 to 98% of the lead in drinking water at the point of use. Lead in the body can cause serious damage to the brain, kidneys, nervous system and red blood cells (Myers, 2004).

Average daily lead intake for adults in the United Kingdom (UK) is estimated at 1.6µg from air, 20µg from drinking water and 28µg from food. Although most people receive the bulk of their lead intake from food, in specific populations other sources may be more important, such as water in areas with lead piping and plumb solvent in water, air near point of source emissions, soil, dust, paint flakes in old houses or contaminated land. Leaded petrol was banned by the European Union because of its effects on human health (Birke *et al.*, 2002).

Zinc

Zinc occurs in small amounts in almost all igneous rocks. The natural zinc content of soils is estimated to be 1-300mg/kg. Zinc imparts an undesirable astringent taste to water. Tests indicate that 5% of a population could distinguish between zinc-free water and water containing zinc at a level of 4 mg/l as zinc sulphate (WHO, 2007). In natural surface water the concentration of zinc is usually below 10ug/l and in groundwater 10-40ug/l. in tap water the zinc concentration can be much higher as a result of the leaching of zinc from piping and fittings containing highly acidic water (Osiakwani, 2002).

Sodium

Sodium levels in drinking water that are less than 20mg/l are considered safe for most people. In the sea coast area however, elevated levels of sodium and chlorides occur naturally due to the proximity to sea water. Substantially higher levels of sodium and chloride may also be due to contamination by activities of man including the use of road de-icing salts, discharges from water softeners, human or animal waste disposal, leachate from landfills and many other activities. Elevated levels of sodium in drinking water does not cause high blood pressure or heart disease, rather only that sodium should be avoided by those who already had such medical conditions (WHO, 2012).

Manganese

Manganese is essential for metabolic processes, but higher levels of manganese may be hazardous to health. It inhibits the use of iron in the generation of haemoglobin. It causes apathy, headaches and insomnia. In extreme cases it causes Parkinson’s disease ((Myers, 2004).

Magnesium

Magnesium is related to water hardness. The degree of hardness in water is determined by the content of calcium and magnesium ions. Hardness is of economic importance because it causes soap not to lather well and it produces scales in boilers. Hard water keeps fish from absorbing heavy metals. It does not have any health impact but affects the taste (WHO, 2012).

2.7.2 Total dissolved solids

Total Dissolved Solids (TDS) represents the amount of inorganic substance and minerals in water. It measures all the materials dissolved in water. It may consist of carbonates, chlorides, iron, magnesium and other parameters. They do not include gases, colloids or sediments. TDs can be estimated by measuring conductance. Conductivity is the measure of the ability of dissolved ions in water to conduct. Higher concentration of TDS causes gastrointestinal irritation in consumers and kidney problems (Nyarko, 2008).

2.7.3 pH

The pH of a solution is the measure of the acidity and alkalinity of a solution. It can be defined as the measure of the concentration of hydrogen ions. Drinking water is recommended to have a pH of 6.5- 7.5 (neutral pH). Acidic pH is very corrosive; it can eat away metal or even human flesh (Nyarko, 2008).

2.7.4 Nitrates

Naturally nitrates come into drinking water supplies through the nitrogen cycle. However most nitrates appear in drinking water as a result of contamination of groundwater by septic tanks, agricultural fertilizers and industrial effluent. Nitrates are reduced to nitrites in the body and causes blue baby syndrome. Reverse osmosis, ion exchange resin and distillation remove 92-95% of nitrates (Amankona, 2011).

2.7.5 Biological oxygen demand (BOD)

Biological oxygen demand (BOD) is a measure of oxygen required by microorganisms in the oxidation of organic matter. Therefore the more organic load the water has, the higher the BOD. Thus it is an indirect measure of amount of organic matter in water. Safe water should have a lower BOD of less than 50% (WHO, 2012).

CHAPTER 3: MATERIALS AND METHODS

3.1 Study Area

Water samples were collected in Harare, Zimbabwe from February 2012 to May 2012. Borehole water was sampled from five boreholes located in the high density suburbs. Municipal water was sampled from domestic water taps and bottled water samples were taken from grocery stores in the city centre. The laboratory analysis of samples was conducted at the Environmental Management Agency Laboratory (EMAL) located in Harare. This laboratory was accredited for ISO 17025 by SANAS and SADCAS in December 2012.

3.2. Experimental design

Each bottled water brand had twelve samples and the same applies to borehole water and municipal water. For each brand, three replicate samples were analyzed each month and the same also applies to municipal and borehole water.

3.3 Sampling

A total of 180 samples were collected in a period of four months. These samples included 60 bottled water samples, 60 borehole water samples and 60 municipal water samples. Bottled water from five different brands was purchased at random taking note of the batch codes so as to increase range of validity. Unrefrigerated bottles were considered for sampling, since borehole water and municipal samples were not taken from the fridge. The purification procedures were considered for each brand. Borehole water was taken from five different boreholes located in five different high density suburbs. Borehole water samples were collected in the early hours of the morning. This was to ensure that the water had not been disturbed much through pumping which can affect the total dissolved solids (TDS) content. The environmental sanitation condition and the human activity around the borehole were noted. The municipal water in this study is treated at one station which supplies the whole Harare.

3.3.1 Sampling procedures

Sampling was done following the sampling procedures used at the Environmental Management Agency Laboratory (EMAL). Thorough sampling procedures were done to ensure that the samples represented the condition of the water at the time of collection. This was done because reliable results depend on the use of proper sampling techniques.

Sampling for bacteriological analysis

Aseptic conditions were maintained during sampling. Sterile 500 ml sampling bottles were used. The tap or / and borehole was run for 2-3 minutes to ensure water is coming from the main line. The tap or/ and mouth of borehole was then flame sterilized so as to kill external bacteria. After flaming, the tap/ borehole was run until it was cool to ensure that bacteria from main line were not killed. The bottles were filled to the shoulder, so as to leave air space for proper mixing before analysis. The bottles were closed tightly.

Sampling for chemical analysis

The tap and / or borehole were run for 2- 3 minutes to ensure water is coming from main line. Two-litre plastic containers were used for sample collection. Collected samples were preserved in a light-proof insulated box containing ice-packs to prevent possible alteration of bacteriological and chemical parameters by light. Sodium thiosulphate was added to municipal water samples on point of sample collection. Sodium thiosulphate keeps bacteria alive by neutralizing the disinfectant effect of residual chlorine. This was done to ensure that the microorganisms remained viable though dormant. Samples were analysed in the laboratory within 24 hrs before bacterial multiplication or colony decline occurred.

3.4 Description of the samples

To protect the reputation of communities and bottling companies the names of the communities and bottled water brands from which water samples were collected will not be disclosed. Therefore communities and bottled water brands in the study were named with letters. The following is the description of the water samples.

Municipal water

Raw water is pumped from Lake Chivero and treated at Morton Jeffrey water works. The water is treated in three main processes before distribution. The raw water is coagulated, filtrated and chlorinated**.**

Bottled water

The bottling companies have different raw water sources and the water is purified differently. The table below shows the bottled water brands, the raw water sources and the methods used for purification of each brand

Table 3.4.1: Raw water sources of bottled water brands and their purification methods

Brand	**Source**	**Treatment**
A	Municipal	Filtration, reverse osmosis and ozonation
B	Municipal	Filtration, reverse osmosis and ozonation
C	Not given	Filtration, reverse osmosis and ozonation

D	Municipal	Filtration, reverse osmosis and ozonation
E	Borehole	Filtration, reverse osmosis, ozonation and carbonation

Borehole water

The boreholes were located at different places with different environmental conditions. The Table 3.4.2 below shows the boreholes sampled the environmental conditions that were around each borehole and the human activities that are carried out close to each borehole.

Table 3.4.2: Boreholes and their respective location

Borehole	Environmental and sanitation conditions
A	Close to a clear undisturbed wetland
B	Surrounded by residential houses (improper waste disposal)
C	Close to home industrial sites
D	Poor maintenance of sewage system and agricultural activities close by
E	A dumpsite nearby and agricultural activities close to the borehole

3.5 Laboratory analysis

The laboratory analyses were done employing the Standard Operation Procedures (SOP) for Chemistry Methods (CM) and Biological Methods (BM) used at EMAL (shown in Table 3.5). To obtain accurate results, standardized quality control samples were available for each parameter. For microbiological tests, negative and positive controls were used for each test.

Table 3.5: Parameters analysed and the methods used (EMAL, 2013).

Parameter	Method	Units
Biological oxygen demand	Electrode SOP/CM 03	milligrams/litre
Conductivity	Electrode SOP/CM 12	Us/cm
Total dissolved solids	Gravimetric SOP/CM 11	milligrams/litre
Total Hardness	Titrametric SOP/CM 36	milligrams/litre
pH	Electrode SOP/CM 27	milligrams/litre
Iron	AAS Flame SOP/CM 22	milligrams/litre
Magnesium	Titrametric SOP/CM 04	milligrams/litre
Manganese	AAS Flame SOP/CM 22	milligrams/litre
Zinc	AAS Flame SOP/CM 22	milligrams/litre
Sodium	Flame photometric SOP/CM	milligrams/litre
Nitrates	Spectrophotometric SOP/CM 23	milligrams/litre
Lead	AAS Flame SOP/CM 22	milligrams/litre
Total coliforms	Membrane filtration method SOP/BM	Number/100ml
Escherichia coli	Membrane filtration method SOP/BM	Number/100ml
Faecal streptococci	Membrane filtration method SOP/BM	Number/100ml
Plate count @ 22^{o}C	Plate count method SOP/BM	Number/100ml
Plate count @37^{o}C	Plate count method SOP/BM	Number/100ml
Plate count @37^{o}C	Plate count method SOP/BM	Number/100ml

Certain measures were observed in the lab to ensure that the microbiological results are not compromised with by contamination from the environment (EMAL, 2012). Disinfectant was used to wipe all surfaces before analysis. Windows and doors were closed during analysis to minimize bacterial contamination from air. In and out movement of people in the lab was restricted. The burner was on during analysis to maintain a sterile environment. All apparatus and agar were autoclaved before use. Positive and a negative control samples were included during analysis of samples (EMAL, 2012).

3.6 Data analysis

The mean and confidence intervals for tested parameters were determined. Using those statistics each bottled water brand, municipal water and each borehole was compared against WHO standards for drinking water for compliance.

CHAPTER 4: RESULTS

4.1 Bottled water

The mean values and confidence interval for the parameters are shown in Table 4.1.1 and 4.1.2. At 95 % confidence interval all 17 parameters for brand A were within WHO standards. For brand B, all the parameters were within WHO standards, therefore for brand B only 15 parameters complied with WHO standards. The mean for plate counts at 22 ^{o}C was 260.8 colonies with a confidence interval of 217.7 - 303.8 colonies. The plate count at 37 ^{o}C had a mean of 221.3 colonies and the confidence interval was 217.7 - 224.9 colonies.

For brand C, 16 parameters complied with WHO standards at 95 % confidence interval. The confidence interval for heterotrophic plate at 22 ^{o}C was 104 - 112 colonies and the mean was 108colonies, this exceeded the recommended limit (100 colonies/ 100ml). For brand D, all parameters complied with WHO standards .For brand E, at 95% confidence interval all parameters were within the WHO standards. Zero bacterial colonies were detected in brand E. All brands tested negative for coliforms (Table 4.1.1 and 4.1.2).

4.2 Borehole water

The mean values and confidence interval for all parameters are shown in Table 4.2.1 and Table 4.2.2. For borehole A, 15 parameters complied with WHO standards. The parameters which did not comply are pH and nitrates. The confidence interval for pH was 5.82 – 591 and the mean value was 5.87.

Table 4.1.1 Mean and 95 % confidence intervals in brackets biochemical parameters analyzed for bottled water

	PARAMETERS (mg l^{-1})								
Sample ID	**BOD**	**TDS**	**ECμS/cm**	**TH**	**PH**	**Fe**	**Mg**	**Zn**	**Na**
WHO standard	6	1000	400	300	6.5 - 7.5	0.3	50	1	100
BRAND A	1.2 (0.96 -1.44)	63.2 (63.06 -63.33)	53.3 (53.05 -53.56)	50.49 (50.29 -50.69)	6.8 (6.53 -7.11)	<0.01	3.38 (3.28- 3.48)	0.17 (0.12 -0.22)	6.28 (6.22- 6.34)
BRAND B	1.03 (0.91 -1.16)	64.54 (64.28 -64.54)	5865 (58.24 -59.06)	51.00 (50.68 -51.32)	6.91 (6.5 -7.32)	0.02 (0.01 -0.03)	3.72 (3.61 -3.84)	0.28 (0.08 -0.47)	5.44 (5.25 - 5.63)
BRAND C	1.38 (1.12-1.65)	64.46 (64.29 -64.63)	56.17 (55.80-56.53)	51.83 (51.65 -52.00)	7.03 (6.63 -7.43)	0.03 (0.01-0.04)	2.66 (2.52 -2.80)	0.11 (0.034 -0.19)	10.36 (10.13 - 10.59)
BRAND D	2.23 (1.64 -2.81)	64.14 (63.78 -64.15)	58.99 (58.57 -59.41)	51.44 (51.31 -51.58)	7.15 (6.83 -7.41)	0.03 (0.02-0.06)	10.17 (9.82 -10.51)	0.3 (0.23- 0.38)	11.08 (10.05 - 12.11)
BRAND E	1.5 (1.16 -1.84)	50.5 (50.4 -50.6)	45.30 (45.14 -45.46)	45.57 (45.41 -45.72)	7.05 (6.79 -7.13)	0.03 (0.02 -0.05)	5.4 (4.8- 6.0)	0.19 (0.14 - 0.23)	7.23 (5.72- 8.74)

Table 4.1.2: Mean and 95% confidence intervals in brackets biochemical parameters analyzed for bottled water

PARAMETERS (mg l^{-1})								
Sample ID	**Pb**	**Mn**	**NO^-_3**	**E. coli**	**T. coliform**	**F. strep**	**HTC@22°C**	**HTC@37°C**
WHO standard	0.05	0.1	10	0	0	0	100	100
BRAND A	<0.01)	<0.01	1.61 (1.37- 1.84)	0	0	0	97.2 (94.8 -99.5)	11.17 (9 - 13.4)
BRAND B	<0.01	<0.01	2.14 (1.97- 2.31)	0	0	0	260.8 (217.7 -303.8)	221.3 (217.7 -224.9)
BRAND C	<0.01	<0.01	1.85 (1.3 - 2.41)	0	0	0	108 (104 -112)	22.2 (19.7 - 24.6)
BRAND D	<0.01	<0.01	2.7 (1.96 - 3.45)	0	0	0	1.92 (1.41 -2.42)	0
BRAND E	<0.01	<0.01	3.01 (2.28 – 3.74)	0	0	0	0	0

For borehole B, only 15 parameters complied with WHO standards. pH and manganese did not comply with WHO standards. The confidence interval for manganese was 0.219 – 0.259mg l^{-1}. At 95% confidence interval all parameters in borehole C were within WHO standards except for iron, sodium, manganese, nitrates, pH and all heterotrophic plate counts. pH exceeded the recommended limit (6.5- 7.5) , the upper bound was 7.81. Iron concentration exceeded WHO standards (0.3 mg l^{-1}), the mean was 1.4 mg l^{-1}. Plate counts 37°C tripled the recommended limit (100 colonies/ 100ml), the range was 319colonies to 332colonies. Therefore 10 parameters complied with WHO standards (Table 4.2.1 and Table 4.2.2).

On borehole D only 5 parameters complied with WHO standards. TDS, EC, iron, magnesium, sodium, lead, manganese, nitrates, pH, *E.coli*, total coliforms and plate counts at 22°C did not comply with WHO standards. Higher concentrations of manganese were detected; with a mean value of 0.347 mg l^{-1} (Table 4.2.1 and Table 4.2.2).

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On borehole E only 7 parameters complied with WHO standards. The parameters which failed to comply at 95% confidence interval are the following; TDS, EC, iron, magnesium, lead, manganese, nitrates, pH, total coliforms and plate counts at 22°C (Table 4.2.1 and Table 4.2.2).

Coliforms were only detected in borehole D and E. All the five boreholes did not comply with WHO standards. Boreholes D and E had the least parameters which complied with WHO standards.

Table 4.2.1 Mean and 95% confidence intervals in brackets of biochemical parameters analyzed for borehole water (in mg l^{-1} were applicable)

SAMPLE ID	BOD	TDS	ECμS/cm	TH	pH	Fe	Mg	Zn	Na
WHO STANDARD	6	1000	400	300	6.5 - 7.5	0.3	50	1	100
BOREHOLE A	2.49 (2.16 - 2.81)	120 (113.17- 126.83)	309.9 (303.8 – 316)	157.17 (153.41 -160.92)	5.87 (5.82 -5.91)	0.24 (0.22- 0.260	26.33 (23.3- 29.37)	0.16 (0.14 – 0.19)	49.08 (47.45 -50.72)
BOREHOLE B	4.28 (4.03 – 4.53)	150.1 (146.44- 153.72)	374.67 (363.12- 386.21)	183.75 (179.99 -187.51)	7.65 (7.49 -7.81)	0.16 (0.14- 0.18)	34.17 (32.37 -35.96)	0.36 (0.34 -0.38)	79.93 (75.83 -83.84)
BOREHOLE C	3.21 (3.06 - 3.35)	152 (147.72 -156.28)	380.33 (373 -387.54)	184 (181.88 -186.12)	6.78 (6.65 - 6.9)	1.4 (1.35 -1.46)	41.67 (39.28 - 44.05)	0.29 (0.25 -0.33)	105.33 (100.36 -110.31)
BOREHOLE D	4.6 (4.33 – 4.87)	1170.25 (1166.58 -1173.92)	442.33 (431.59 -453.1)	184.67 (81.37 -187.97)	5.89 (5.78 -5.99)	1.63 (1.58 -1.67)	53.92 (52.47 -53.36)	0.51 (0.44- 0.58)	100.33 (92.25 - 108.41)
BOREHOLE E	4.74 (4.19 -5.28)	1180.83 (1177.93 -1183.74)	473.67 (467.47 - 479.86)	184.58 (182.6- 186.56)	4.87 (4.83 – 4.9)	1.24 (1.22 -1.27)	62.67 (60.95 -64.39)	0.99 (0.95 -1.04)	90.33 (83.08 - 97.59)

Table 4.2.2 Mean and 95% confidence intervals in brackets of biochemical parameters analyzed for borehole water

	PARAMETERS (mg l^{-1})							
SAMPLE ID	**Pb**	**Mn**	**NO^-_3**	**E.coli**	**T. coliform**	**F. strep**	**HTC@22°C**	**HTC@37°C**
WHO STANDARD	0.05	0.1	10	0	0	0	100	100
BOREHOLE A	<0.01	0.131 (0.116 –0.146)	11.58 (10.27 -12.90)	0	0	0	21.5 (18.87 -24.13)	6.17 (3.9 -8.43)
BOREHOLE B	<0.01	0.239 (0.219- 0.259)	8.77 (8.18 -9.35)	0	0	0	52.17 (49.43 -54.8)	68.58 (64.55 -72.62)
BOREHOLE C	0.014 (0.013 -0.016)	0.34 (0.321 -0.361)	12.69 (11.9 -13.49)	0	0	0	148.5 (141.04 -155.96)	326 (319.96- 332.04)
BOREHOLE D	0.133 (0.113 -0.152)	0.347 (0.321 -0.372)	21.92 (21.19 -22.66)	0.67 (00.10 -1.23)	4.67 (2.86 -6.47)	0	116.25 (112.75 -119.75)	66.33 (61.85 -70.82)
BOREHOLE E	0.146 (0.132 -0.16)	0.424 (0.392 -0.457)	17.29 (16.33 -18.26)	0	1.33 (0.42 -2.25)	0	256.17 (241.56 -270.78)	66.42 (62.52 -70.31)

4.3 Municipal water results

For municipal water, at 95% confidence interval, all the parameters complied with WHO standards. Table 4.3 below shows the results in full details.

Table 4.3: Results for municipal water chemical and microbiological analysis

Parameter	WHO standard (mg l^{-1})	Mean (mg l^{-1})	95% Confidence interval
BOD	6	2.64	2.34 - 2.95
TDS	1000	97.63	93.89 – 101.37
EC µS/cm	400	348.15µS/cm	341.12 – 355.18µS/cm
TH	300	118.62	116.03- 121.2
pH	6.5- 7.5	7.18	7.07 - 7.29
Fe	0.3	0.19	0.18- 0.21
Mg	50	12.71	12.34 - 0.32
Zn	1	0.29	0.27- 0.32
Na	100	38.73	36.9 – 40.47
Pb	0.05	0.023	0.019 – 0.025
Mn	0.1	0.046	0.032 – 0.061
NO_3	10	3.22	0.032 – 0.061
E.coli	0	0	0
T.coliforms	0	0	0
F.*streptococci*	0	0	0
PC@22°C	100 colonies/100ml	2.36 – 5.44	3.9
PC@37°C	100 colonies/100ml	8.29 -16.84	12.57

CHAPTER 5: DISCUSSION

5.1 Municipal water

In municipal water all the 17 parameters analysed complied with WHO standards. Therefore according to the parameters analysed in this study, Harare municipal water is safe potable water that does not pose health threats to consumers.

The microbiological safety of municipal water could be attributed to the residual disinfection effect of chlorine and the efficacy of chlorine as a disinfectant (Hassan *et al.*, 2011). The consistency of the microbiological and chemical quality of Harare municipal water over four months proves consistency in application of effective adequate treatment procedures. Contamination along distribution pipes to consumer taps may occur due to biofilm formation and leakages since Harare pipes are old (ZINWA, 2012). However since the microbial quality complied with WHO standards it shows that the residual chlorine was adequate to decontaminate the water in cases of recontamination.

In a previous study in Portugal by Christensen and Nissen (2011) microbiological and chemical parameters exceeding the WHO recommended limit were detected. Christensen. and Nissen (2011) noted that inadequate treatment and disinfection process results in deteriorated microbial and chemical quality of water.

The leaching of metal in distribution pipes compromises the chemical quality of water (Vreeburg and Boxal, 2007). This study shows that leaching in distribution pipes, if any, did not affect the chemical quality (metals). Acidic pH contributes to the leaching of pipes by corroding the internal lining (WHO, 2012). In this study the pH was within WHO recommended limit (6.5-7.5), this partly explains why the metal parameters are within WHO standards.

5.2 Bottled water

In all bottled water brands in this study, all chemical parameters complied with WHO standards. This indicates that the purification procedures used by bottling companies in Harare are effective and are followed consistently. This also indicates that the raw water source used by the different brands is of good quality. The source of raw water for bottled water has an influence on the purified water quality because some chemical impurities in raw water may persist in water even after purification (Hunter, 2007).

All brands tested negative for coliforms and faecal streptococci. Absence of coliforms suggests that the water does not contain microbiological agents that may pose health problems such as gastrointestinal diseases (Svagzidiene and Page, 2010). This shows that the bottling companies are implementing purification processes that eliminate and destroy bacteria. The findings of the microbiological results in this study are attributed to the efficacy of filtration and reverse osmosis which reduce bacterial load while ozonation and or carbonation disinfect the water (Svagzidiene and Page, 2010).

As for heterotrophic bacteria all the brands complied with WHO standards except for brands B and C. Brand B had higher concentrations (of heterotrophic plate count bacteria both at 22 ^{o}C (217- 303 colonies/ 100ml) and 37 ^{o}C (217- 224 colonies/100ml). This indicates heavy bacterial load in this brand. It is therefore not suitable for drinking because it has exceeded the recommended limit (100 colonies/100ml) set by WHO. The water can cause waterborne diseases such as typhoid in consumers (Grant, 2007). Brand C had a confidence interval of 104

- 112 colonies /100ml for HTC at 22^{o}C. This also makes the water unfit for human consumption because it did not comply with WHO standards (100 colonies/ 100ml) WHO (WHO, 2012).

In previous studies, coliforms were detected in bottled water. Bharat (2003) found that 5% of the bottled water in E was unfit for human consumption. The 1.5% of the brands contained coliforms. Out of 23 brands of bottled water in India, one of the brands contained presumptive coliforms and tested positive for *E.coli*, therefore it was unfit for human consumption (Laul and Kaur, 2011). Kasenga (2010) detected total coliforms in 4.6% of brands and found faecal coliforms in 3.6% of brands in Tanzania. Hassel and Capil (2011) demonstrated that consumers should not assume that all bottled water sold is satisfactory. In their study, 1 brand out of 23 brands did not microbiologically comply with WHO standards. Comparing the results of this study to other studies, it can be seen that Harare bottled water brands are much better because there is no evidence of faecal contamination.

The levels of heterotrophic bacteria for brands B and C in this study could be attributable to poor hygiene practices by the bottling companies. Raw water source could not have been source of contamination given that the raw water source for B is similar to that of A and D which complied with WHO standards for HTC. Also the purification processes used by brands A and D are the same as those used by B and C and, therefore if the purification processes managed to produced safe water (brand A and D) it could not be responsible for the contaminates in B and C. Therefore microbial quality of brands B and C could have been compromised by unhygienic practices during manufacturing. While filtration and reverse osmosis can reduce the microbial load of water, there are chances of contamination if filtration equipment is not maintained properly (Laul and Kaur , 2011). Unsterile packaging bottles contaminate the purified water after bottling. Sterility of bottles can be achieved by rinsing bottles in ozonated water, subjecting bottles to high temperatures, caustic washing and/ or autoclaving (Siwela *et al.*, 2002).

The type of treatment given to water prior to bottling has an influence on the microbial load of water (El- Bantonti, 2011). This explains why no bacteria were detected in Brand E which was subjected to both ozonation and carbonation. Brand E is double disinfected, the microbes which escape ozonation are killed by carbonation, thus all microbiological parameters complied with WHO standards in brand E. Unlike ozonation, carbonation has residual disinfection effects which lasts until the bottle is opened (Grant, 2007). Therefore no bacteria were detected in brand E. Ozonation does not have residual effects which kill bacteria that grows during shelf life. This explains why heterotrophic bacteria (even at low counts) were identified in all the brands which were disinfected by ozonation alone.

This finding is supported by (Hunter, 2007). He demonstrated that carbonated waters are of good quality, he surmised that this was mostly likely due to CO_2 antibacterial activities. Hunter (2007) confirmed an outbreak of cholera associated with consuming non carbonated water. Growth of bacteria after bottling is well documented, therefore other than poor manufacturing practices, the microbial quality of brands Band C may be attributed to bacteria that grow after bottling. This shows the need of a disinfection process which confers residual disinfection throughout the shelf life of bottled water and also the need of sterilizing bottles before filling in water.

The sources of the detected heterotrophic bacteria in this study are not very well established; they could be derived from unhygienic practices or proliferated after bottling. Therefore the limitation of this study is the failure to test the presence of simple nutrient requiring bacteria that may grow after bottling. The test would help us to know the origin of heterotrophic bacteria. Examples of simple nutrient requiring bacteria are *Flavobacterium* and *Pseudomonas* species, which proliferate during storage of water. *Pseudomonas* species resistant to antibiotics were isolated in bottled water brands sold in many different countries such as Tanzania (Kasenga, 2010) and India (Laul and Kaur , 2011) just to mention a few.

In a previous similar study in Bulawayo by Siwela *et al.* (2002), sixty samples from three Zimbabwean bottling companies were used. 12 % of the samples tested positive for coliforms therefore did not comply with WHO standards. These findings suggest that bottled water purification is generally improving in Zimbabwe because in 2002 coliforms were detected but in the current study no coliforms have been detected.

5.3 Borehole water

pH

The pH level for borehole C (6.65 – 6.9), complied with WHO standards (6.5- 7.5). The pH for boreholes A, D and E was below the recommended limit, the water was slightly acidic. Borehole B had slightly alkaline water. Acidic and alkaline pH is not good for human health. Neutral pH of 6.5 to 75 is the safest pH for human consumption. Continued consumption of acidic or alkaline water causes gastrointestinal corrosion resulting in ulcers (WHO, 2007). Therefore boreholes A, B, D and E are not suitable for human consumption since they pose health threat due to their failure to comply with WHO standards for pH.

Nitrates

Boreholes A, C, D and E had high levels of nitrates. The concentration exceeded the recommended limit of 10 mg l^{-1} set by WHO. Boreholes C, D and E were located close to industrial sites, leaking sewage pipes, and gardening and dumpsites areas respectively. Therefore the borehole water could have been contaminated by nitrogen compounds from the industrial areas, dumpsites, sewage and gardens. Surface water act as a recharge point for ground water through leaching, infiltration, percolation and seepage (Myers, 2004). This means that when nitrates are elevated in the surface water, the groundwater nitrates are then likely to increase (Amankona, 2011). Similarly, Moyo (2009) found high nitrate levels in boreholes located close to pit latrines and farming areas in Bulawayo, Zimbabwe

The real cause of high nitrate concentration in borehole A could not be ascertained because the borehole was located close to an undisturbed wetland. Further research should be done to determine the cause of the unexpected high nitrate levels given that wetlands have good flora and fauna components which purify groundwater.

High nitrate levels are detrimental to health especially in infants. Nitrates are reduced to nitrites in the stomach of infants. The resultant nitrite oxidizes haemoglobin to methaemoglobin (metHB) which reduces the capacity of haemoglobin to transport oxygen around the body (WHO, 2012). Reduced oxygen transport becomes clinically manifest when the metHb concentration reaches 10% or more of normal haemoglobin. The condition causes cyanosis and at higher concentration it causes asphyxia (Myers, 2004). Therefore the boreholes that did not comply with WHO standards (10mg l^{-1}) are unsuitable for potable uses by humans.

Iron

Heavy metals in excess are pollutants which are distributed in the environment; the source is mainly weathered rocks. However metals have increased due to human activities, there infiltrating into the ground aquifer as rainwater that serves as groundwater source, resulting in the contamination of groundwater.

Boreholes C, D and E had higher levels of iron that did not comply with WHO standards (0.3 mg l^{-1}). Iron is essential for health because it transports oxygen in blood. In as much as higher iron concentration is not hazardous to human health; it is not permitted in potable water because it is considered as a secondary or aesthetic contaminant. The findings for boreholes C and E are related to the environmental conditions. Borehole E was located closed to a dumpsite which contained metal waste from which iron can be leached by rainwater into the ground aquifer. Borehole C was located close to industrial site, the by- products of the industrial activities contributes to groundwater contamination. The industrial site has many activities such as carpentry, welding and rubber making just to mention a few. Nyarko (2008) documented that the corrosion of the metal borehole pipe with water can cause metal contamination in borehole water.

Sodium

Boreholes C and D did not comply for sodium concentration with WHO standards (100 mg l^{-1}). Sodium contamination results from human activities, such as improper disposal of waste (O'Neil 1999). In this study sodium concentration in boreholes C and D could be attributed to the industrial sites, leaking sewage systems and agricultural lands which are close to the boreholes.

Manganese

Boreholes B, C, D and E had higher levels of manganese than WHO standards. Borehole E had the highest manganese levels of 0.424 mg l^{-1}. Nyarko (2008) suggested that high manganese concentration could be attributed to underlying geological rock. Similarly, the high concentration of manganese for boreholes B, C, D and E could have been attributed to the underlying geological rocks.

Lead

Boreholes A, B and C complied with WHO standards for Pb concentration but Pb concentration in boreholes D and E exceeded WHO standard (0.05 mg l^{-1})$^{.}$ These findings could be attributed to the natural and anthropogenic sources. The dumpsites in the location of borehole E contained metal waste that have the potential of contaminating groundwater. The high Pb concentration could also be attributed to acidic water which corrodes borehole pipes. The pH for borehole D is acidic (5.78- 5.99) and borehole E is acidic as well (4.83 – 4.9), thus the water is capable of corroding pipes.

Consumption of water heavily polluted with Pb can cause Pb acute poisoning. However this rarely occurs. Rather Pb can bioaccumulate in the body causing damage to the brain, kidney, and red blood cell. Lead can also affect the nervous system retarding biochemical reactions (WHO, 2006). Some studies suggest that there may be a loss of up to 2IQ points for an increase in blood Pb concentration (WHO, 2012). Therefore water from boreholes C and D is not suitable for domestic use.

Magnesium and total hardness

Boreholes D and E had higher concentration of magnesium. The concentration did not comply with WHO standards. Higher concentration of magnesium is related to water hardness. However the total hardness for borehole D and E complied with WHO standards.

Total dissolved solids

Total dissolved solids in boreholes D and E did not comply with WHO standards (1000 mg l^{-1}). TDS has a direct relationship to EC because it gives an account of all the dissolved ions in water. This relationship explains why boreholes D and E had Mg, EC and TDS concentration not complying with WHO standards. Higher concentration of TDS is an indication of water pollution (Amankona, 2011), therefore boreholes D and E are polluted. The factors which attributed to ground water pollution are; the poorly maintained sewage system (at D), the dumpsite (at E) and the agricultural activities both at D and E. These factors supply ions into the groundwater and if occurring at once it results in elevated TDS and EC values.

Heavy concentration of TDS affect the palatability of water and do pose health threats to human if it exceeds 1000 mg l^{-1} (WHO, 2002), therefore the consumer for boreholes D and E are likely to be affected health wise. The consumers are likely to suffer from gastrointestinal irritation. This water is unsuitable for people with heart and kidney problems, congenital heart disease. The consumption of high levels of salt causes salt and water retention in the body. This in turn may result in increased blood pressure, hypertension and cardiovascular related diseases in consumers after prolonged use (WHO, 2002). Therefore water from boreholes D and E is not potable.

Microbial quality

In all boreholes faecal *streptococci* was not isolated. Other pollution indicator organisms (coliforms) were identified in D and E. (Nyarko, 2008); also identified coliforms ranging from 0.5 to 20 colonies /100 ml thus detection of coliforms in groundwater has been documented before. The heterotrophic plate counts for boreholes C, D and E exceeded WHO standard (100 colonies/ 100ml), this indicates heavy bacterial load in the water. The presence of coliforms is an indication of human and faecal waste contamination and increased infiltration of bacteria (Nyarko, 2008). Therefore the coliform and heterotrophic bacterial contamination in D and E is attributed to the poorly maintained sewage system and the manure in the agricultural lands. Borehole C has heavy bacterial load indicated by a mean of 326 colonies at 37^{o}C and 148.5 colonies at 22^{o}C. The heterotrophic bacteria in borehole C could be attributed to biofilm which form in the pipes and underground.

Boreholes A and B complied with WHO standards in all microbiological parameters. This finding is attributed to the water purification ability of wetlands since borehole A is located in an undisturbed wetland. It is also because soil has greater ability to filter off and trap off bacteria from groundwater (Nyarko, 2008).

Given other factors TDS, EC and TDS also have an influence on bacterial growth. pH ranging from 3 to 10.5 favours the growth of indicators and pathogenic organisms (Hassel and Capil, 2011). Higher TDS and EC promote bacterial growth. TDS is constituted of salts and minerals which are growth factors for bacteria. Boreholes D and E had TDS and EC which exceeded the WHO standard. Boreholes C, D and E had pH values lying between 3 and 6.9 thus it encouraged bacterial survival.

Boreholes C, D and E did not comply with WHO standards for the microbiological parameters. The consumers of this water are prone to diarrhoea and other gastrointestinal diseases. Hence the water is unsuitable for human consumption. Incidentally there have been discontinuous outbreaks of diarrhea which could have been attributed to the poor borehole quality.

5.4 Conclusion

The main objective of this study was to assess the potability of bottled, borehole and municipal water produced in Harare. The compliance of each sample type with WHO standards for given parameters was analysed. The aim of the evaluation these different sources of drinking water were to ascertain the safety of these three sources of water.

Coliforms and *streptococc*i were absent from all five brands, thus the water is free from human and animal contamination. All the brands, all chemical parameters complied with WHO standards. In three brands (A, D and E) out of the five brands, all 17 parameters complied with WHO standards. In brands B and C, heterotrophic plate counts did not comply with WHO standards. The failure of compliance could be attributed to poor hygienic standards during the manufacturing processes. It is concluded that brands B and C are not suitable for human consumption because of the high bacterial content which cause gastrointestinal infections. Carbonated water (brand E) is the safest bottled water to drink because no bacteria were detected in the water. The conclusion is that three out of the five brands produced in Harare complied with WHO standards. Therefore not all bottled water brands are safe.

A number of parameters did not comply with WHO standards in all boreholes. Therefore the boreholes in Harare are not chemically and microbiologically safe for human consumption. All parameters complied with WHO standards in municipal water. This shows that the water treatment process and hygienic practices currently used by Harare City Council is effective in producing high quality potable water.

This study has shown that of all the three drinking water sources in Harare, municipal water is the safest water to drink since all parameters complied with WHO standards. It has shown that not all bottled in Harare is safe. However carbonated water proved to be much safer.

Harare borehole water is unsafe for human consumption. The groundwater quality could be compromised by environmental conditions and sanitation.

5.5 Recommendations

There should be improved surveillance system for the bottled water industry in Harare to ensure that Good Manufacturing Practices (GMP) is done effectively. All water bottling companies need to take necessary precautionary measures because any lapse in hygiene may lead to microbial proliferation.

Water from all the five boreholes is unsuitable for domestic use as it exposes consumers to health problems. Therefore to mitigate this problem the Environmental Management Authority (EMA) and stakeholders should take measures against pollution activities which cause groundwater contamination.

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